Psychophysical investigations of perceptual learning and attention

Summary

Perceptual learning is conceptually tightly linked with memory and attention. Memory in the context of perceptual learning typically refers to the retention of enhanced performance following training. Attention is an important mechanism for information selection during skill learning, and consequently seen as a pre-requisite for intentional (perceptual) learning. The research presented in this thesis focuses mostly on visual perceptual learning and includes investigations of the contribution of attention and awareness to visual skill. In addition, the research presented also includes one project focusing on the attentional mechanism itself, exploring the relationship between microsaccades and attentional selection. The initial chapters focus on the contributions of low-level visual cortex to visual perceptual leaning (*Chapter 2*) and on the role of attention and awareness (*Chapter 3*). The following chapters address questions related to consolidation and interference (*Chapter 4*) and to the role of attention and awareness in interference (*Chapter 5*). In a last empirical chapter, a study is presented that focuses on the possible contribution of microsaccades to information selection during attention-demanding tasks (*Chapter 6*). Finally, the findings from the thesis are summarized and what they contribute to the current literature is discussed (*Chapter 7*).

First, we tested hypotheses regarding the *extent of the neural network contributing to orientation discrimination learning*. In **Chapter 2** we found large generalization of orientation discrimination skill, which, however, was not complete: There was limited but significant orientation and position specificity, measured as an advantage in performance when tested on the specific orientation and position used in training, compared to testing at other positions/orientations. This advantage however was much smaller than the total magnitude of learning progress over 15 sessions of orientation discrimination training. Our studies support the view that specificity is most strongly related to asymptotic learning, as only the amount of late learning was predictive of both position and orientation specificity. Overall, the psychophysical data thus confirm some important notions such as a certain degree of specificity, which is achieved during asymptotic learning. In **Chapter 3** we investigated to what extent different preconditioning strategies led to spatial transfer of learning from a previously trained location, and how long-lasting these potentially advantageous effects of preconditioning were. We found that during initial generalization testing, there was only an advantage of

the pre-tested condition over the unstimulated condition. However, for the second to fourth session, masked exposure yielded lower thresholds than either pre-tested or no-stimulation positions, irrespective of whether passively exposed stimuli had random or identical orientation offset to the stimulus used in the simultaneously performed task. From the fifth session onwards there was no difference between the four different exposure conditions. The data from Chapters 2 and 3 when combined suggest a complicated cooperation of read-out and low-level plasticity that does not necessarily agree with the original conceptions of neither the lowest-level theory nor the reverse hierarchy theory of perceptual learning. At the same time, proponents of double training paradigms seem to misinterpret the predictions of lowest-level and reverse hierarchy theories, thereby creating ill-posed theoretical oppositions.

Next, we investigated the *nature of the process that leads to the stabilization of visual skill memory*. Our data from **Chapter 4** showed that 15 sessions of training (spread over 4-5 weeks) were not enough to sufficiently consolidate memory traces to avoid subsequent interference by another task. Thus, a classical consolidation interpretation of the data seems improbable. In addition, modelling data showed best agreement with empirical data when the proportion of neurons consolidating was set to 0%, providing further support for re-recruitment of overlapping populations in different tasks as an explanation for behavioral interference. Hence, behavioral interference is determined by population overlap, and not by the status of a time-limited consolidation process and accordingly not by the time interval between tasks. Furthermore, we found in **Chapter 5** that passive interference (by exposure to stimuli presented outside awareness) did not have an effect on existing memory traces for orientation discrimination at the 135° reference orientation. This indicates that the connectivity state induced by an attentively executed task cannot be easily influenced by competing but more subtle adaptation like effects induced by passive exposure. It is only when competing stimuli were shown first outside awareness (passive exposure) that there was interference with subsequent acquisition of orientation discrimination at the 135° reference orientation. This effect was highly time-dependent, suggesting a quickly decaying state of adaptation induced by passive exposure.

Finally, in **Chapter 6** we investigated the *link between attention, microsaccades and the attentional blink effect*. Our results showed a robust inhibition of microsaccade rate 200-300ms after presentation of the first target, the time window commonly associated with the attentional blink effect. Subsequently, a rebound of microsaccade rate was observed which coincided with increases in detection performance of the second target. Both the extent of microsaccade inhibition and microsaccade rebound were significantly correlated with participants' performance of detecting the second target letter at the time interval where the attentional blink was greatest. One possible interpretation of the results is that temporary withdrawal of attentional resources goes along with an inhibition of microsaccade rate.

Taken together, our data confirmed the importance of asymptotic learning to induce specificity. This provides the proper context to interpret a number of recent studies suggesting that skill can be generalized easily across stimulus dimensions and locations. Our data also show that while there is an exposure aspect and an associated adaptation state that can contribute to perceptual learning and interference, these effects are small compared to the contribution of attention. Interestingly, we found that effects of passive exposure could be taken advantage of by latter attentive learning, but that the benefit was limited to early learning. Since the passive exposure most likely induced effects in low-level areas, this shows that read-out mechanisms have access to these early levels from the beginning of learning. On the other hand, the effects of passive learning do not transfer to asymptotic learning, again emphasizing the importance of combining exposure with attention for normal skill learning. These findings emphasize the importance of interactions between read-out and bottom-up stimulation, but in a manner not predicted by current theories of perceptual leaning. Moreover, we present evidence that memory traces can be reactivated and modified, even after many weeks of training, adding evidence against consolidation models of learning. Finally, we have suggestive evidence for the contribution of microsaccades in the allocation of attention, which, if confirmed, opens important questions about the contribution of modifications in temporal patterns of microsaccades to improvements in skill performance as a function of daily training.